

# Very Low Frequency Remote Sensing Measurements of the Lower Ionosphere at Site of the United Arab Emirates

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Received: 11 September 2007 / Accepted: 3 July 2008 / Published online: 20 December 2008  
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**Abstract** The proposed research project is aiming for providing basic data for quantitative comparison of lightning-induced disturbances of the ionosphere and the radiation belts in the American, European and Asia sectors. Most of the current data on such phenomena has so far been obtained in the western hemisphere, and the weight of scientific information indicates that lightning-induced effects at high altitudes and in the radiation belts may dominate other processes on a global scale. The proposed research project will facilitate the establishment and conduct of Very Low Frequency observations in the United Arab Emirates as a part of the Asia sector, thus providing a basis for comparison to facilitate global extrapolations and conclusions. Under the proposed project, Stanford University partners with Sharjah University, deploying one of their Very Low Frequency receivers at Sharjah University campus. Sharjah University provides the data digitization and recording equipment to facilitate continuous acquisition of the data. All data from the proposed project will be available for analysis over the Internet, and a series of annual visits are planned to maximize interactions and information exchange between the two universities.

**Keywords** VLF receiver · Lower ionosphere · UAE

## 1 Introduction

The Stanford University Very Low Frequency (VLF) group, in the electrical engineering department, is engaged in studies of electromagnetic phenomenon in the ionosphere and magnetosphere. Among the chief methods employed for these studies is the placement of receiver systems tuned for VLF frequency ranges (30 Hz–50 kHz).

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Figure 1 shows how remote sensing with VLF receivers is used to study the lower ionosphere known as the D-region at altitudes below  $\sim 90$  km. Precipitating electrons  $>100$  keV generate ion-electron pairs in the lower region (D-region) of the ionosphere that lead to changes in the conductivity. These changes in conductivity can be detected through the monitoring of amplitude and phase of VLF transmitters, operated by various navies around the world for long range communications. The “narrowband” data can be extracted in real-time from the broadband, 100 kHz sampling data also made available by these VLF receivers.

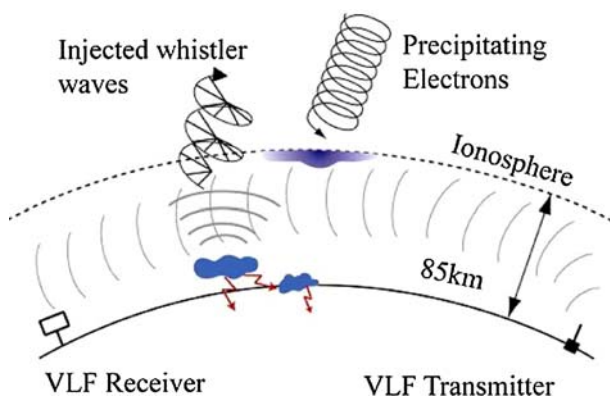
A disturbance in the D-region between transmitter-receiver paths is due to a cosmic, solar, or terrestrial source and manifests itself as a change in the received signal, followed by a characteristic recovery time. These ionospheric disturbances can be due to a wide variety of phenomenon, including heating from lightning strikes, solar flares, cosmic gamma-rays, natural, and manmade electron precipitation, magnetospheric whistler waves, and more.

VLF is the most useful way to engage in studies of the ionospheric D-region. Traditional methods such as radar scatter, ionosondes, etc., have been unable to produce many results on the nature of the D-region due to the relatively small electron count. VLF waves, however, reflect very efficiently from the D-region, and thus are an excellent medium for study.

In recent years, Stanford University has set up and operated an array of VLF receivers at multiple locations across the USA, known as the Holographic Array for Ionospheric Lightning (HAIL). The array has been an invaluable source of new information about the nature of various ionospheric disturbances, and studies are getting closer to quantifying and classifying the physical nature, spatial extent, and contribution to radiation belt losses associated with lightning induced electron precipitation (LEP), as well as other phenomenon.

Though the HAIL array has produced significant results on lightning over the continental USA, it is unable to quantifiably study the thunderstorms occurring over other parts of world. Recently, Stanford University has begun setting up VLF receivers around the European continent, in order to make the same quantification studies, and begin a basis for comparisons among different regions of the world.

The present research study would greatly enhance the ability for ionospheric imaging over Europe, and would begin to provide a picture of the nature of thunderstorms over



**Fig. 1** The principle configuration of the VLF remote sensing measurements to study the localized ionospheric disturbances over a specific region

Asia, and even central Africa. In this context the proposed research project would include establishing a new site for monitoring such phenomena at Sharjah in the United Arab Emirates (UAE) with the collaboration and technical support of the VLF group of Stanford University. This new site would provide: first, an important comparative data for verification of the various parameters that affecting the behavior of the thunderstorms over the USA and Europe. Second, the collection of accumulating measuring data could be utilized for building the ionospheric imaging over the Arabian Peninsula and center of Asia.

## 1.1 Review and Analysis of Related Work

Subionospherically propagating VLF waves are uniquely suited for the investigation of the nighttime D-region, (40–100 km altitudes), so named due to the difficulty of making systematic measurements (Sechrist 1974).

Subionospheric VLF measurements are particularly responsive to the study of this altitude range because the nighttime reflection height is in the vicinity of  $\sim 85$  km altitude. Measurements of the amplitude and phase of VLF signals propagating in the earth-ionosphere waveguide have long been used effectively for remote sensing of the ionosphere. VLF sounding has been established as a sensitive tool for the measurement of ionospheric conductivity, especially at altitudes below 90 km (e.g., Sechrist 1974), and in recent years has been extensively utilized to study a variety of lower ionospheric disturbances, including those associated with lightning discharges (Inan et al. 1993; Inan 1993; Burgess and Inan 1993), heating by HF (Bell et al. 1993) and VLF waves (Rodriguez et al. 1994), the auroral electro-jet (Kikuchi and Evans 1983; Cummer et al. 1997), and relativistic electron precipitation enhancements (Demirkol et al. 1999).

Over the last two decades, two different primary types of subionospheric Very Low Frequency Signatures have been identified; The first one : the early/fast VLF conductivity changes in which the subionospheric VLF signal amplitude/phase changes within  $<20$  ms of the causative lightning flash, indicating an immediate effect of the lightning discharge in the overlying lower ionosphere, (Inan et al. 1988a, b, c). The second type is the VLF signature of lightning-induced electron precipitation (LEP) events, in which the subionospheric VLF signal/amplitude changes after an onset delay of  $\sim 1$  s with respect to the causative lightning flash, consistent with the finite wave and particle travel times, respectively to/from the regions of maximum cyclotron resonant pitch angle scattering of the energetic ( $>100$  keV) radiation belt particles. This causes them to precipitate into the lower ionosphere (Burgess and Inan 1993).

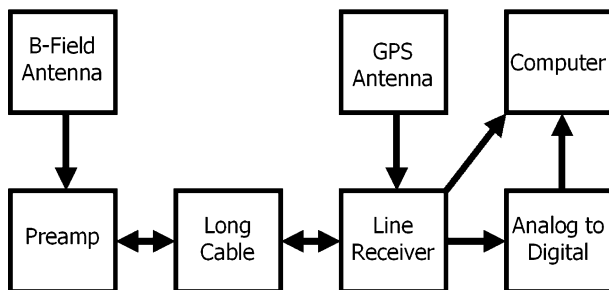
## 2 Implementation of the Present Project

### 2.1 Brief Background

As already stated in the previous paragraph, the VLF measurements are particularly useful as a sensitive tool for the measurement of ionospheric conductivity, especially at altitudes below 90 km.

Mainly two different primary types of subionospheric signals of VLF have been used to monitor the various phenomena associated with ionospheric disturbances. These are early/fast VLF conductivity changes and LEP Events (Stanford, Internal Report, 2002).

**Fig. 2** The block network of the system for mentoring, collecting and storing the data at the campus of Sharjah University



**Fig. 3** The location of UAE with respect to other counties in Asia and Africa continents

## 2.2 Methods of Inquiry and Analysis

Events of both types will be regularly measurable at the Sharjah University site with a collaboration of the research team at Stanford University. These measurements will allow the quantitative determination of any significant differences between the European and the American hemispheres, thus enabling the scientists to better assess the role of lightning-driven electrodynamic coupling between upper atmospheric regions on a global scale. In this context, it is important to note that the monitor equipments that will be installed at Sharjah university must be Stanford-built, so to ensure it is identical in every way to those utilized at other sites distributed all over the world.

The main objective of this proposed research project is to initiate a research program designed to address outstanding scientific questions concerning transient and localized variations of the nighttime lower ionosphere (<90 km) in the context of a cooperation between the University of Sharjah in the UAE and Stanford University in the USA.

Accordingly the proposed project must follow the well established methodology adopted by the Research team of Stanford University. This includes the deployment of the VLF receiver equipment at the Sharjah University campus in cooperation with the scientists from Stanford University. This initial scientific cooperation is essential in view of the highly specialized nature of the proposed measurements, which have been pioneered by the researchers at Stanford University during the past two decades. The block diagram of the installed system is shown in Fig. 2.

### 2.3 Significance of the Project

The proposed project will greatly enhance the ability for ionospheric imaging over the UAE, and will begin to provide a picture of the nature of thunderstorms over Arabia, and even the Middle East, Far East, and Center of Africa. The following map, as shown in Fig. 3, highlights the significance of the proposed new site for such measurements.

**Acknowledgment** The authors are acknowledge the support of Sharjah University for funding of the project and Stanford University for providing all necessary information needed to establish the site at Sharjah University campus. Also we thank Mr M. Cohen of Stanford University for revising the manuscript of the project.

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